Impact of Cargo Loading on Bulk Carriers

John E. Kokarakis\(^1\), Gijsbert de Jong\(^2\)

\(^1\) Bureau Veritas, Greece, john.kokarakis@gr.bureauveritas.com
\(^2\) Bureau Veritas, France, gijsbert.de-jong@bureauveritas.com

Abstract

Harmonization of bulk cargo loading and de-ballasting rates in today’s fast paced terminals is a prerequisite for a safe and efficient operation. Ship and terminal partnership can achieve safe and high performance cargo loading and discharge. Incorporation of design criteria to improve loading efficiency is necessary. The safety record of loading at high rates remains unblemished.

1. Introduction

The insatiable appetite of developing countries for iron ore and coal has placed high demands for fast loading and discharging of bulk carriers. Tough market conditions impose intense operational demands on the bulk carriers which transport 30\% of the world’s ocean cargo. In particular, iron ore and coal cargoes present high physical demands on the ship structure. Terminals, ship owners and class societies share responsibility to minimize risk in bulk carrier operations. Many bulk carriers can lead particularly demanding working lives. Cargo grabs, bulldozers and hydraulic hammers may cause physical damage to plating, frames and brackets. In loading ports where the cargo delivery rate is high, the inability to pump out ballast water sufficiently fast may result in the hull being over-stressed. High density cargoes give little or no internal support to the (inner) sides of the cargo holds, thereby magnifying the effects of panting. The scouring effect of abrasive and corrosive cargoes may cause hold coatings to deteriorate rapidly.

Fig. 1: Loading in Terminal

Loading rates as high as 16,000 tones per hour are not uncommon, limited mostly by the de-ballasting capacity of the vessel. A typical proportion between de-ballasting and loading rate is one over two. The problem of high loading rates has been escalated with the increased demand for commodities and the commercial pressure to maximize terminal throughput. In recent years ship owners have increasingly reported pressure to load vessels at high rates in a compressed time frame. High rates of loading were identified as a risk factor during the revision of bulk carrier regulations in the late 1990s leading to the publication of International Association of Classification Societies (IACS) and International Maritime Organization (IMO) guidance. The challenge today is ensuring international regulations and guidance are adhered to.

Terminals demand vessels with high ballasting and de-ballasting capacity. Vessels which do not comply are excluded. The design criteria of a modern bulk carrier should include loading flexibility, even at low draughts, in order to facilitate compliance with increased demands for speed of loading and unloading. Terminals ask for light ballast, about 60\% of the normal ballast in order to accelerate loading as depicted in Figures 1 and 2. Light ballast might be associated with inadequate maneuverability and stability. Given that light ballast is associated with aft trim in order to facilitate de-ballasting; maneuvering becomes more critical (BMT, 2008).

Fig. 2: Terminal Uploading
The tools available to the master to monitor the accuracy and adequacy of the loading of his ship are the on-board loading instrument, the loading and unloading sequence manual, and possibly a real-time stress monitoring. In addition, a draught survey towards the end of loading process might be a critical verification tool. This study looks into the problems associated with the cargo loading of bulk carriers from the viewpoint of loading rate, accuracy and number of pours, as well as operational aspects. The main particulars of bulk cargo loading are analyzed and checklist-type recommendations are presented.

2. Special Precautions for Various Bulk Cargoes

Bulk carriers are transporting a wide variety of cargoes. It is necessary to understand the characteristics of each commodity. The bulk cargo diversity, although commercially highly attractive, imposes a wide variety of operational and equipment requirements on the vessel.

Materials like grain have peculiar characteristics and loading requirements. The need to control vermin and dust requires special consideration. Dust also becomes a serious hazard as the dust from most grains, particularly hard grains like red sorghum, when mixed with air in the right proportion becomes an extremely explosive mixture. Grains are liable to heat and/or sweat, especially if damp, when they may germinate or rot. Grains having angles of repose of less than the critical 35 degrees are prone to shifting at sea (stability issue).

In case of coal cargo, under no circumstances should the hatches be opened or the hold ventilated or entered during the voyage. The atmosphere above the coal cargo should be monitored for the presence of methane, oxygen and carbon monoxide. Readings should be taken at least daily and if possible at the same time. The oxygen level in the hold will fall from an initial 21% over a period of days to stabilize at levels of the order of 6-15% in a sealed hold. If the oxygen level does not fall below 20% or rapidly increase after an initial fall, it is possible that the hold is inadequately sealed and is at risk of spontaneous combustion. A rapid increase of carbon monoxide by about 1000 ppm per day is another risk indicator, in particular if it is accompanied by an increase in methane levels. The temperature in a brown coal briquette cargo in a well sealed hold normally remains at 5-10 degrees C above sea water temperature due to diurnal breathing of small air quantities. A rapid increase of about 20 degrees over 24 hours is evidence of spontaneous combustion. Coal dust also tends to ignite with sparks or heat sources. The remedy is to keep coal dampened down. On the other hand excessive wetting causes cargo shifting at sea (bulk cargo liquefaction). Coal ventilation should be directed at the surface area only. Moreover, coal with high sulphur content is liable to create sulphuric acid from the reaction with water carried by sweat. Sweat is formed when the water vapor in the air condenses into water droplets following air cooling below its dew point. The acid will corrode the side shell and frames.

Granular materials have void spaces caused by irregular shape of the particles. These void spaces may be filled with air and/or water. When cargo with moisture is carried at sea, cargo particles compress the void spaces and pressurize any free water present in the spaces (pore water pressure). Moisture may also be released from the mineral structure of some types of cargo, increasing the amount of free water in the cargo and therewith the pore water pressure. If the pore pressure is high, it might overcome the friction forces which bind the individual particles of material. Then, the shear strength of the cargo falls to the point where liquefaction occurs. The cargo becomes a viscous fluid with the ability to flow with detrimental effect on the ship stability.

In this respect it is important to refer to the International Maritime Safety Bulk Cargo Code (IMSBC Code), which was adopted by IMO in December 2008, (IMO, 2008), through Resolution MSC. 268(85) and addresses the special hazards associated with solid cargoes in bulk when they are shipped: structural damage due to improper cargo distribution, liquefaction of cargo (causing loss of stability during the
voyage) and chemical reaction of cargoes. The IMSBC Code, which serves to facilitate the safe stowage and shipment of solid bulk cargoes by giving information on the possible dangers and instructions on carriage procedures, will enter into force as a mandatory regulation on 1 January 2011, and will effectively replace today’s voluntary BC Code.

Steel cargoes can be split into products that are packed or wrapped, like steel coils, and those that are not, like for example steel beams, angles and plates. The steel cargoes have to be well ventilated and kept dry before loading. Wet cargo in the holds increases humidity in the air and vapor pressure. It leads therefore to moisture damage to cargo. Hatch covers and all other deck openings should be closed to stop any rain getting into the holds. Care should also be taken not to load incompatible cargoes such as chemicals, fertilizers, sulphur-bearing or hygroscopic materials in the same compartment as steel cargo.

Steel coil loading assessment involves longitudinal hull girder strength in intact and flooded conditions, as well as inner bottom plating and stiffener local strength. Coil cargo shown on Figure 3, typically results in very large bending moments following flooding according to UR S17, given that a large mass of water will ingress into the hold. The coil loading conditions are controlling the design with regard to compliance with the UR S17 requirements. Utilization of dunnages will give rise to a patch load type on the double bottom structure. As the load is not uniformly distributed, the coil loading capacity cannot be found by simply multiplying the tank top area by the allowable inner bottom (tank top) load (t/m²). The patch loading pattern of the coils is similar in nature to the loads exerted by wheels on ro-ro ships. Sometimes dunnages are placed on steel billets spanning two adjacent floors and dunnages are placed directly above floors. That way the load will not be transmitted on the inner bottom plate and stiffeners. It will be directly carried by the primary grillage structure of the double bottom. The design is in general dictated by the length and weight of the coils, the number of dunnages to be used for each coil as well as the number of tiers of coils typically ranging from one to three. It is noted that the type of dunnages, e.g. steel or wood, is not critical as opposed to their number supporting a coil. The CSR rules promulgate that use of more than 5 dunnages is equivalent to a uniform distributed load (IACS, 2008).

3. Loading

The submitted loading plan should provide the following information before commencement of the loading operation:

- Cargo characteristics, amounts and properties;
- Characteristics of loading/unloading equipment, number, range of movement and loading/unloading rates;
- Depth of water alongside the pier;
- Water density at berth and any air draught restrictions;
- Maximum sailing draught and minimum draught for safe maneuvering;
- Conveyor belt delivery amount beyond ship stoppage signal;
- Terminal requirements for moving ship;
- Relevant port restrictions on bunkering and de-ballasting.

The amount and type of cargo will dictate the stowage plan. Ballasting/de-ballasting should be enacted simultaneously on symmetrical port-starboard tanks to prevent undesirable torsion effects. The plan should provide at each step:

- Cargo quantity per hold;
- Amount of water ballast per tank;
- Draughts at completion of each step;
- SWSF and SWBM at each step;
- Time for completion of the step
- Assumed de-ballasting and loading rates;
- Allowances for any operation stoppages.

The crew need to plan and monitor the rate of loading, the weight of cargo to be loaded and how it is to be measured, any vessel shifts that will be necessary and draught surveys to confirm the weight of cargo loaded. Crew must also ensure that the vessel is safe at the intermediate stages of loading. A key issue with loading rates is the number of passes made during the operation. A large number of passes minimizes the potential for overloading at the expense of more time needed to complete the operation. Ballast tanks must be sounded to verify content and ballasting/de-ballasting rate. Loading practices, when carried out according to an accurate loading plan, do not seriously affect the ship safety. On the opposite, unloading with the employment of heavy grabs and bull-dozers, is a contributing factor to the ship structural damage. Hatch coamings, bulkheads and the lower brackets of main frames are prone to damages. The repeated impact of a 35 ton grab
must be inevitably endured. As a considerable amount of cargo is unreachable by the grab, a bulldozer is lowered into the hold to move the bulk cargo from the outer parts of the hold into the area which is accessible to the grab/discharging equipment. This is a time-consuming and costly operation.

Cargo should not be loaded high against one hold bulkhead or one side and low against the other (uneven distribution). In general, each hold should be loaded using at least two separate pours per hold, as only few ships have been designed for single pass loading. An accurate record of the mass loaded in each pour into each hold should be maintained by the terminal. Sudden increases in the loading rates, potentially causing significant overloading, should be avoided. Pour means the quantity of cargo entered into the hold through one hatch opening within one step of the loading plan, i.e. from the time the spout is positioned over a hatch opening until it is moved to another hatch opening. Trimming the cargo is the partial or total leveling of the cargo within the holds by means of loading sprouts or chutes, portable machinery equipment or manual labor. The trimming to the boundaries of the cargo space minimizes the risk of cargo shifting at sea. On the other hand, trimming the ship is the adding, removal or shifting of weight in a ship to achieve the required forward and aft draughts.

Loading steps are the cargo/ballast configurations in which one or a group of holds have been loaded or unloaded, with an adequate ballast pattern to ensure that shear forces and bending moments remain within permissible harbor limits. A loading sequence is a succession of loading steps. The sequence is built up step by step from commencement of cargo loading to reaching full deadweight capacity. A next step is starting each time the loading equipment changes position to a new hold. Each step is to be documented and submitted to the class society for review. In addition to the longitudinal strength, the local strength at each hold needs to be considered. The target is to utilize two pours and two trim pours for all cargoes and not only for the high density ones. Utilization of one pour per hold might be detrimental from the standpoint of longitudinal strength, as indicated in the example presented on Figure 4. In this case loading of hold No 3 of a capesize bulk carrier in a single pour results in exceeding the allowable limits for the shear force (124% at the forward bulkhead and 145% at the aft bulkhead, respectively). In case of de-ballasting the corresponding ballast tank No 3 before loading of cargo hold No 3, the corresponding shear force maxima fall down to 95% and 125%, as depicted on Figure 5. Another study considers the effect of a 5 minute “worth” of cargo overshoot on the bending moments and shear forces. Figure 6 depicts the shear force increase in the condition with the overloaded cargo hold No 3.
hold only is partially filled, due to increased risk of cargo shifting.

In order to safely load the ship, the loading sequence pour by pour must be such as to ensure that strength and stability requirements are met at all times during the process. To this end the (approved) loading instrument can be used in addition to the (approved) loading manual to check draught & trim, still water bending moment & shear force and cargo weight in each hold during intermediate loading stages. Key points to be taken into account are the cargo loading rate and de-ballasting flow rate. In order to prevent exceedence of strength and stability requirements as a result of the occurrence of deviations during the loading process, it is recommended to keep a safe margin to the allowable limits when planning the loading sequence pour by pour. In addition it is recommended, that the vessel condition is not assessed only at the start and the end of a step but also at intermediate times during the step to ensure that the limits are not exceeded. In principle, the above remarks are also valid for unloading, although the duration of unloading is usually much larger than for loading, which provides additional reaction time to unexpected events.

In order to ensure safe and efficient loading with the minimum number of hatch changes, there are details relating to the operation of the ship that need to be taken into consideration. These include the vessel’s buoyancy at the wharf (depends on the density and temperature of the ocean at that location), whether the ship is part-loaded, in ballast or lightship condition, the ship’s loading plan, the loading rate versus ballast discharge rate, as well as the number and position of holds to be loaded. An important factor is the order in which the holds are loaded. The shear force imposed on the hull must be correctly managed to avoid failure. It is necessary to stage loading to distribute the stresses as evenly as possible. The recommendation by IMO to fit Hull Strength Monitoring devices can improve the loading operation. Monitoring utilizes sensors and processors to display real-time information to the officer-in-charge of the loads the ship experiences during loading and unloading.

In some ports the quantity of cargo loaded is determined by draught survey. This method is subject to significant errors and may result in overloading. Many terminals now handle vessels substantially larger than the original design of the berth and its equipment. At such berths, limitations on draught, air draught and trim can result in increased stress conditions during loading and discharging (e.g. due to loading aground). The inability to adequately trim cargo may result in uneven cargo distribution or list which requires additional ballast to correct. The accuracy of the draught survey depends on the accuracy of the data. The draught marks should be read with an accuracy of no less than 1 cm. The density of the sea water is to be measured as accurately as possible. The quantity of ballast water is to be checked by sounding all ballast tanks and void spaces. The density of ballast water needs to be measured as well. The full set of fuel soundings is also necessary. At least two draught surveys are made before beginning the loading sequence, as well as after finishing it. Several intermediate draught surveys are also to be performed. The second survey is generally placed at the end of a pour simultaneously with the complete end of the ballast sequence and after completing the stripping. It can be used to check the accuracy of the weighing equipment ashore. The ship is to have trim by the stern to facilitate stripping. The displacement is computed on the basis of certain corrections, due to the location of the draught marks, the deflection of the ship (as a beam), the trim of the vessel and the density of the seawater. It is advisable that the displacement computation from the draught measurements is computerized.

The loading efficiency of the ship is a complex function of loading rate, number of pours, vessel strength and de-ballasting capacity (main and stripping). The average loading rate is defined as the total cargo loaded divided by the elapsed time from start to finish. The nominal loading rate indicates the capacity of the individual ship loader. Number of pours indicates how often a hold is touched in the process. Synchronization means that de-ballasting should finish before the end of the loading.

4. Terminal and Ship Interaction

Bulk terminals and bulk carriers are interdependent. They share mutual concerns regarding safety and efficiency. The ship/shore interface should be governed by a partnership spirit and not an adversarial one. Understanding bulk carrier design and operating limits – and working closely together – ship and shore personnel become partners for safer shipping. Terminal and ship need to agree and follow procedures prior to the ship’s arrival. Information needs to be exchanged
between the ship and the terminal. Procedures regulate the communication and information exchange between the ship and the terminal also after arrival and prior to commencement of the cargo loading/unloading.

Optimized loading modes by terminals result in increased loading rates. As a consequence of the high loading rates the de-ballasting flow rate needs to be high as well. Therefore, both the cargo loading as well as the de-ballasting operations need to be closely monitored and any deviations need to be readily recognized in order to enable timely mitigation of the potential consequences. If a slower rate of de-ballasting decelerates or even stops the loading operation, the time lost does not count as lay-time. Vessels are typically permitted only one de-ballasting stop. If they exceed their de-ballasting time by more than four hours, they may not be accepted by the terminal in the future.

It is clear that the human element is critical in this process. Well trained staff, effective use of the loading instrument, careful control of the cargo loading equipment process and good communication between ship and shore are essential. There are several key junctures in the process where the human element may be addressed. The crew and shore personnel need to understand the properties of the cargo being loaded for example. The cargo will dictate the extra precautions, structural capacity and stowage and trimming requirements. Loading operations contribute to damage and overloading when they are accompanied by poor communications between the ship’s crew and terminal staff.

Recognizing that a number of accidents had occurred as a result of improper loading and unloading of bulk carriers the IMO adopted the Code of Practice for the Safe Loading and Unloading of Bulk Carriers (the BLU Code) with Resolution A.862 (20) in 1997 (IMO, 1997); this was followed by MSC/Circ.1160 Manual on Loading and Unloading of Solid Bulk Cargoes for Terminal Representatives in 2005 (IMO, 2005). The purpose of the BLU Code is to assist persons responsible for the safe loading or unloading of bulk carriers to carry out their functions and to promote the safety of bulk carriers. It applies to the loading and unloading of solid bulk cargoes to or from bulk carriers of more than 500 gross tonnage. It does not apply to ships which are not bulk carriers by definition, ships carrying grain and ships which are being loaded using shipboard equipment only. The BLU Code contains a requirement for the terminal to check the suitability of a vessel to its facilities before it arrives. Such requirement is indirectly connected with terminal liability and has pushed terminals towards vetting inspections, similar to the ones of Rightship, prior to accepting a candidate ship.

The ship officer-in-charge should submit the proposed loading/unloading plan to the cargo terminal representative at the earliest opportunity. The loading plan should include considerations of the loading sequence to manage hull girder strength and stability, ballast operations (again for strength and stability reasons) and any inspections to be completed and the loading rates and levels. SOLAS Ch VI, Part B, Regulation 7 dictates that the loading plan is lodged with the Port State Control authorities. The terminal must provide the officer-in-charge with the loaded cargo mass at frequent intervals and at the end of each pour. The draught checking must be implemented through an agreed procedure. The operation can commence after the Master receives from the local maritime authorities a Certificate of Readiness. He always has the right to stop the operation if he has reasons not to be satisfied.

If there is a deviation from the loading plan the officer-in-charge should take corrective actions to restore the original plan. Cargo operations should not be resumed until the modified plan is agreed between the officer-in-charge and the terminal representative. Sometimes terminal may alter the submitted loading plans to accommodate their own operational requirements. In June 2000, the “ALGOWOOD” buckled, while loading sand and aggregates at Bruce Mines, Ontario in Canada. The operation followed a predetermined sequence, which was modified in the field, when the vessel was unable to shift as far aft in the berth as called for. Later studies confirmed that the bending moment at the time of failure was 2.3 times the allowable SWBM (TSBC, 2000).

In order to meet the terminal instructions a ship must come alongside with ‘bare minimum’ ballast. Typically, this results in a condition representing approximately 60% of the normal ballast condition in the loading manual, with a corresponding large trim, less than 100% propeller immersion and high windage area. Under these conditions, there is increased difficulty in swinging the vessel at low speeds due to the increased windage area and a worsened turning performance due to the
reduced turning levers from the large stern trim as shown comparatively on Figure 7, (BMT, 2008). With large stern trim the hydrodynamic pivot point moves aft and the turning lever is reduced. The reduction in rudder area combined with the reduced capability of the propeller also reduces the steering forces that the rudder can apply. The efficiency of the emergency fire pump is also severely tested under light ballast conditions. All of these factors serve to reduce the maneuverability, and hence safety, of the ship.

5. Checklist for Loading Process

1) Is the depth of water at the berth and the air draught adequate for the cargo operations to be completed?
The depth of water should be well established over the whole area the ship will reside. The terminal must be well aware of the vessel’s air draught requirements. If the loaded draught presents a marginal under-keel clearance, the Master needs to confirm the safety of his vessel. The terminal usually provides information on the density of the water at the berth site. Air draught is the distance between the water surface and the upper extremity of the ship (for example, the tip of an antenna). It is critical to determine if the ship can pass under a bridge or to assess the height required under the loaders or unloaders.

2) Are mooring arrangements adequate for all local effects of tide, current, weather, traffic and craft alongside?
Adequate fendering arrangements should be provided. The ship has to be well secured in her moorings. Mooring lines must be kept taut. Attention should be given to the movement of ship caused by tides, currents, passing ships or by the operation in progress.

3) In an emergency is the ship able to leave the berth at any time?
The ship should be able to move on its own at short notice. Low tides, excessive trim or drafts, lack of tugs and main engine immobilization are factors which may prevent a vessel to leave at short notice. Nevertheless the method of emergency un-berthing should be agreed in advance. If emergency lines are needed, the terminal should be aware of their position and method of securing.

4) Is there safe access between the ship and the wharf?
The means of access between ship and wharf must be safe and readily available. They should consist of a gangway or accommodation ladder with a safety net underneath it. Access equipment must be supervised due to changing drafts during the operation. The gangway/ladder should not be under the path of cargo being transferred. It should also be well illuminated and equipped with a lifebuoy with a heaving line nearby.

5) Is the agreed communications system between ship and terminal operative?
Communication must be maintained between the responsible officer on board and the terminal representative ashore. The selected system of communication, as well as the language to be used, phone numbers and/or radio channels have to be recorded in the checklist.

6) Are the liaison contact persons during operations clearly identified?
Effective communication between ship and terminal is absolutely necessary. The names of the persons of authority and their mode of contact need to be recorded in the checklist.

7) Are adequate crew on board and adequate staff in the terminal for emergency?
Sufficient crew is needed in order to deal adequately with a potential emergency. The signals to be used in such an event, either ashore or on board, should be clear to all parties involved.

8) Have any bunkering operations been advised and agreed?
Bunkering should be coordinated with the cargo operations and terminal agreement needs to be confirmed.

9) Have any intended repairs to wharf or ship while alongside been advised and agreed?
Hot work from welding, burning or flame operations may require a hot work permit and possibly a gas free certificate in the case of OBO carriers. Even if hot work is not planned, work on deck might impede the operation.

10) Has a procedure for reporting and recording damage from cargo operations been agreed?
Accumulation of damages on the steel work of the vessel leads to loss of strength and needs to be documented for prompt repair.
11) Has the ship been provided with copies of port and terminal regulations including safety and pollution requirements and details of emergency services?
A fact sheet containing this information should be passed to the ship on arrival and should include any local regulations controlling the discharge of ballast water, if any.

12) Has the shipper provided the Master with the properties of the cargo in accordance with the requirements of Chapter VI of SOLAS?
The ship needs to know the grade of cargo, particle size, quantity to be loaded, stowage factor and moisture content of the cargo. The BC Code and its mandatory continuator the IMSBC Code provide guidance on these aspects. The ship should be also appraised of any material which may contaminate or react with the cargo and ensure that the holds are free of such material.

13) Is the atmosphere safe in holds and enclosed spaces to which access may be required, have fumigated cargoes been identified and has the need for monitoring of atmosphere been agreed by ship and terminal?
Steel rusting, potential spontaneous ignition in coal cargoes and other phenomena may cause a hazardous atmosphere in the hold. Oxygen depletion in the holds, fumigation gas transferred with the cargo and leaking out of the hold can generate explosive atmospheres or have toxic effects on the crew.

14) Have the cargo handling capacity and any limits of travel for each loader/unloader been passed to the ship?
The number of loaders/unloaders to be utilized needs to be agreed upon in advance and their capabilities need to be understood by all parties involved. The agreed maximum cargo transfer rate must be recorded in the checklist. Furthermore, limits of travel of loading equipment should be indicated, especially if the ship needs to be shifted to another position during the operation. The accuracy of weighing devices is critical and needs to be checked frequently.

15) Has a cargo operations plan been calculated for all stages of loading/de-ballasting or unloading/ballasting?
The plan should be prepared before arrival with all necessary information provided by the terminal. A necessary step in the manual is compliance of the bending moments and shear forces at each step with the (approved) permissible values.

16) Have the holds to be worked been clearly identified in the loading/unloading plan, showing the sequence of work and the grade and mass of cargo to be transferred each time the hold is worked?
This information needs to be communicated in a clear methodical and orderly manner.

17) Has the need for trimming of cargo in the holds been discussed and the method and extend been agreed?
Usually spout trimming is employed with satisfactory results. Bulldozers, front-end loaders, deflector blades, trimming machines or even manual trimming can be also utilized. The extend of trimming depends on the nature of the cargo.

18) Do both ship and terminal understand and accept that if the ballast/de-ballast operation is not synchronized with the cargo operation, it will be necessary to suspend cargo operations to remedy the situation?
The target is to load or discharge the cargo possibly without any stops. This is, however, a case of potential overstressing of the hull if the ballast/de-ballast operation is out of step. If the maximum permissible loading rate of the ship is lower than the capacity of the terminal, it may be necessary to include pauses in the cargo operation or to ask the terminal to operate their equipment at less than the maximum capacity. In case of very cold weather the possibility of frozen ballast lines needs to be factored in.

19) Have the intended procedures for removing cargo residue, lodged in the holds while unloading been explained to the ship and accepted?
Bulldozers, front-end loaders or pneumatic/hydraulic hammers should be used with care since they can cause structural damage. Prior agreement regarding the method and the supervision of the operation is necessary.

20) Have the procedures to adjust the final trim of the loaded ship been decided and agreed?
The actual quantities and positions to be utilized to achieve the final ship’s trim will depend upon the draught readings taken before the conclusion of loading.

21) Has the terminal been advised of the time required for the ship to prepare for sea after completion of cargo work?
The time to secure hatches on completion of the loading operation may vary depending on the time of the day or night and the weather conditions.

6. Hazard Identification During Loading

Hazards are introduced due to high shear forces and bending moments caused by alternate hold loading. High density cargoes
cause high local stresses, particularly in shear under alternate hold or block loading pattern. They also lead to loss of buoyancy or structural failure if the holds are flooded. Grain and sugar cargoes can produce explosive dusts. High loading rates lead to possible loss of control of loading condition with consequent high stresses. Continued overstressing has a cumulative effect on fatigue. Vulnerability to internal damage during cargo loading and discharging operations also leads to protective coating damage, accelerated corrosion and local structural failure.

Terminal staff needs to share with the ship crew an awareness of the following risks/hazards during the cargo operations.

**Deviations from the Loading Manual**
Exceeding permissible limits may lead to catastrophic hull failure. It is noted that local over-stressing can occur even if global longitudinal strength criteria are satisfied.

**Shallow draught loading**
The largest number of non-successive cargo pours should be employed for each hold.

**High loading rates**
The terminal must be prepared to stop operations if the officer-in-charge of the ship is concerned about deviations from the agreed plan. Risk associated with high loading rates can be assessed by studying the sensitivity of the hull girder to overshooting/overload.

**Asymmetric cargo and ballast distribution as depicted on Figure 8, (IACS, 1997)**
Heavy cargo poured into a cargo space at one end of the hold piles up. The lateral pressure acting on the transverse bulkhead increases, since it will not be cancelled out. Stowing cargo asymmetrically about the centerline causes twisting and warping of the hull girder. Asymmetric distribution of ballast causes torsional loads which may lead to cracking at the hatch corners or at the hatch end beams and upper ballast tanks. Sometimes the additional torsional loads may also cause buckling of the cross deck. High density cargo is recommended to be stowed uniformly over the cargo space and trimmed to level the cargo and minimize the risk of damage to the hull structure and cargo shift in heavy weather (stability). Symmetric ballasting/de-ballasting is recommended (in PS/SB pairs).

**Lack of effective ship/shore communications**
The ship-to-terminal communications link should be maintained throughout the cargo operation.

**Exceedance of load line marks**
End-hold trimming to maximize cargo carrying capacity and bring the ship down to her marks is to be avoided since it may result in overloading of end holds.

**Partially filled ballast tanks**
Sailing with partially filled ballast tanks is to be prohibited unless the approved Loading Manual permits such loading conditions. Partially filled ballast tanks are subject to sloshing loads due to the ship moving in a seaway. Sloshing magnifies dynamic internal pressures and may damage the internal tank structure.

**Inadequate cargo mass measurement during loading**
It is important to accurately determine the cargo mass loaded into each hold. At high loading rates terminals without suitably positioned cargo weighing equipment need to stop the operation to allow draught surveys and displacement calculations to be carried out to verify compliance with the agreed loading plan. The terminal has to inform the ship of the remaining amount of cargo on the conveyor belt that must be loaded after a STOP from the vessel.
Structural damage

Cargo handling equipment, like the one shown in Figure 9, can damage the hull structure through impact loads (grabs, hydraulic hammers, etc.) and by damaging protective coatings. Structural damage and coating breakdown will weaken the structure and ultimately pose a threat to the structural and watertight integrity.

7. Effects of Overload

Loading control issues are the potential deviation from the loading plan due to overshoooting or de-ballasting out of synch with the time allowed to catch up with the cargo loading. Control of loading is essential in order to remain within the limits of the plan. It is noted that a five minute over-pour might result in a 1300 t overshooting of cargo. There is also limited time to stop and take draught readings, exacerbated by potential bad weather. Calculations typically are performed under static conditions and assuming symmetric loading, which might not be the case. Furthermore, the possibility of reduced section modulus due to corrosion to a percentage as high as 10% needs to be addressed in the calculations as dictated by the CSR for bulk carriers.

A study carried out by Bureau Veritas showed that a 5% overload placed in various holds could increase the SWBM significantly, (BV, 1995). A 10% overload can increase the SWBM by up to 80% and shear force by up to 26% as indicated in Table 1 for various sizes of bulk carriers. This 10% overload can be caused by a five to eight minute delay in stopping a conveyor belt with a capacity of 16000 tons per hour. These percentages skyrocket if the load overshoot is combined with an error in the longitudinal center of gravity of 5% of the hold length for two holds. The resulting percentages are depicted in Table 2. It is also observed that the impact of errors in loading and load distribution is amplified as the vessel size increases.

<table>
<thead>
<tr>
<th>Vessel Size</th>
<th>Bending Moment Variation %</th>
<th>Shear Force Variation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capesize</td>
<td>79</td>
<td>18</td>
</tr>
<tr>
<td>Panamax</td>
<td>60</td>
<td>26</td>
</tr>
<tr>
<td>Handymax</td>
<td>32</td>
<td>19</td>
</tr>
<tr>
<td>Handysize</td>
<td>38</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 2: Load Variation due to LCG Error

In addition to the increased risk, there is the issue of the local strength of the inner bottom plating and stiffeners, which are experiencing significant impact loads during cargo loading at high loading rates. Dry bulk cargoes are typically loaded by conveyors and may be dropped from height levels above the main deck with consequent high impact loads on the inner bottom (tank top), in particular at the start of loading with high density cargoes. To this end Bureau Veritas has performed an internal study into the effects of iron ore loading of a typical capesize bulk carrier with a loading rate of 16,000 tones per hour, free falling onto the inner bottom from a representative drop height of 26 m as depicted on Figure 10. In order to compute the impact load the falling cargo can be considered as an incompressible liquid jet diverted on a
perpendicular surface (the inner bottom). As the load is applied suddenly (when the first cargo hits the inner bottom), dynamic amplification has been taken into account as well. Assessment of the scantlings of the inner bottom plating and longitudinal stiffeners of the bulk carrier shows that typically the inner bottom plating thickness has significant margin compared to the class required value, while the stress levels in the stiffeners also remain well within permissible limits.

8. Design Issues related to Bulk Carrier Loading

The main design issue is related to increased loading flexibility. The combination of improved loading flexibility with a high safety level is governed by how much you can fill a given cargo hold relative to what you have in the neighboring holds at the current draught. The shear force in way of a transverse bulkhead is ruled by the difference in downward acting forces from the cargo hold forward of the bulkhead relative to the upward acting force from the cargo hold aft of the bulkhead. The loading flexibility was increased by the introduction of IACS Unified Requirement UR S25 ‘Harmonized class notation and standard loading conditions’ in 2003. UR S25 imposes the computation of the following important loading parameters:

- Allowable cargo intake in each individual cargo hold as a function of the actual draught;
- Allowable cargo intake for two adjacent cargo holds as a function of the actual draught.

Fig. 11: Shear Force in Alternate Load Pattern

The structure is sensitive to net vertical load acting on the double bottom as shown on Figure 11 for the alternate loading pattern. The net vertical load is the difference between the downward weight of cargo mass in the hold, ballast water in double bottom tanks in way of the cargo hold and the upward buoyancy force which is dependent on the draught. Overloading of the cargo hold combined with insufficient draught causes excessive net vertical loads on the double bottom which can distort the structure in way of the hold. The cargo carrying capacity of a hold is reduced with a reduction in the mean draught. Allowable loads for each individual cargo hold or combined allowable loads for two adjacent cargo holds are provided as function of the local draught. These loads are applicable in seagoing condition and during loading/unloading in harbor.

As a general rule, when contracting a new vessel, the envisaged operating patterns should be fixed as early in the initial design stage as possible in order to incorporate possible multi-port conditions in the specification. Critical structural design aspects to be considered are:

- The deck and bottom transverses should be in line forming a stiff ring, while hatch-end beams should not be eliminated;
- Hatch openings are longer and wider to facilitate loading, reducing the size of the cross deck strips leading to torsion-induced stresses at the hatch corners;
- Use of higher tensile strength steel at the deck and bottom, catalyzes buckling and fatigue damage. The reduced thickness in the design also amplifies the impact of corrosion.

Another design criterion can be the minimization of the impact of loading accuracy or inaccuracy on the strength. Loading volumes are not estimated precisely. Ship capabilities lag far behind the capability of terminals to meet commercially agreed loading rates. Questions have been posed whether to include a minimum ballasting performance as a design criterion in bulk carriers. Requirements should be considered for redundancy, accessibility, remote monitoring and operability of all parts of the ballast system in order to ensure that full de-ballasting capability is available during the loading process. Increased ballast line friction in older vessels does not allow the utilization of the rated pump capacity. Reduced size of the ballast piping contributes to the increase of pressure losses. The pump operating point (head-flow rate) is determined by the intersection of the pump curve and the system curve as shown in Figure 12. The maximum fluid velocity in the ballast pipes should be 3 m/s. One pump has to serve two tanks simultaneously to reduce the water velocity in the branch line and keep it within limits. Branch lines with the same diameter like the main line increase the efficiency of the system. A practical solution is to use one pump to de-ballast a pair of port/starboard tanks. Due to the aft trim the forward tanks are the most critical. The loading-unloading manuals should include pressure losses and stripping time.
Electric power availability and ballast water treatment systems might also affect de-ballasting efficiency.

![Fig. 12: Pump Operating Point.](image)

Conditions on-board are frequently slippery due to spillage of cargo. It is thus advisable from the operational standpoint to strategically place guard rails and stanchions on hatch covers and around hatch openings. Ships should be suited to their operational environment and the design has to satisfy ship/cargo compatibility.

### 9. Conclusions

The variety of cargoes that are carried by the bulk carriers impose a variety of requirements related to the safety of the ship and the well-being of the cargo. Special ventilation and stowage rules of thumb need to be employed depending on the type of cargo. This fact makes the bulk carriers the most diverse vessels today, but at the same time the most difficult to design.

In addition to these complications, increased operational demands by modern terminal practices impose a heavy toll on the capacity of bulk carriers and stretch their limits to the maximum. A vessel needs to have a clear loading plan beforehand and work in harmony with the terminal personnel. The design needs to accommodate various critical features in order to enhance the loading efficiency. The vessel has to be compatible with the intended cargo. A risk and hazard identification can provide valuable conclusions on the tolerance of the ship to errors or mishaps. It is a design target to achieve a relative insensitivity to overshoots and asymmetric load distributions. The impact of loading errors is amplified as the size of the vessel increases.

A vessel is optimized if a cargo hold can be filled with one pour, maybe two. The design problem is further entangled due to the dynamic nature of cargo loading. Nevertheless, the design criterion should be the increase of the loading flexibility, which is a complex function of the loading rate, the number of pours and trims, the vessel strength and the de-ballasting capacity including stripping.

Loading flexibility is enhanced with the increase of ballasting/de-ballasting capacity and the synchronization with the cargo loading. Hydraulic marriage of the ballast pumps with the on-board piping arrangement should be employed in order to determine with accuracy the operating pump pressure and flow rate.

Cargo monitoring, communication and exchange of information between ship and terminal, crew training and familiarization with the loading procedure and incorporation in the design of all extra criteria for flexibility and safety are “sine qua non” to obtain the most attractive bulk carrier.

### 10. References

Bureau Veritas, 1995, ‘Recommendations to Avoid Overloading of Bulk Carrier Structures’, Guidance Note NI 402

IACS, 1997, ‘Guidance and Information on Bulk Cargo Loading and Discharging to Reduce the Likelihood of Over-stressing the Hull Structure’, Recommendation 46

IMO, 1997, ‘Code of Practice for the Safe Loading and Unloading of Bulk Carriers’ (BLU Code), with IMO Resolution A.862 (20)

TSBC, 2000, Transportation Safety Board of Canada, ‘Structural Failure Bulk Carrier ALGOWOOD’, Report No M00C0026, June 2000, Bruce Mines, Ontario


